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Munich, August 24, 2000
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Abstract

Designation of the invention

The relates to a method and a device for the complete correction of visual defects in the human eye. Combinations of measuring and processing methods have been specified which, when used according to the present invention, enable the human eye to be completely corrected. In doing so, measuring methods are used which can precisely measure the surface of the cornea and which also record the aberrations arising in the further optical path up to the retina. The computer-aided evaluation of these measuring results, in conjunction with the calculation of ideally corrected eye lenses (for example, after cataract operations) or of ideally correcting cornea surfaces, makes it possible to manufacture a patient-specific lens and/or to shape the cornea in an ideally correcting manner, preferably using a spot scanning excimer laser system in a topography-aided manner.

Description

Method and device for the complete correction of visual defects in the human eye

[0001] The invention relates to a method and a device for the complete correction of visual defects in the human eye.

[0002] In ophthalmology, it is known to shape the cornea by ablation of tissue in the case of amblyopia. In this context, the data on the aberration in the optical path of the eye is obtained by questioning the patient about his/her subjective impression of vision on the basis of corrections via standardized corrective lenses in front of the eye of the patient. Besides, methods exist for measuring the outer contour of the eye with the assistance of stripe- or ring-projection systems as are manufactured, for example, by the Orbtek, Tomey, or Technomed companies.

[0003] German Patent Application DE 197 05 119 A1 describes a method for improving a Shack-Hartmann sensor which can be used in the field of astronomy to measure wavefronts for surveying stars.

[0004] In German Patent 197 27 573 C1, a device and a method for shaping surfaces, in particular of lenses, by laser ablation of the surfaces is specified in a valuable contribution to the technological development.

[0005] It is felt to be a disadvantage of the related art that the correction of the lenses takes place only on the basis of suboptimum data on the causes of the visual defects such as irregularities of the cornea surface or aberration in the optical path. Consequently, only corrections according to the standard lens formulas of geometric optics are carried out.

[0006] Therefore, the object of the present invention is to provide a method and a device which permit complete correction of all refractive visual defects, including the aberrations of the optical path in the defective eye.

[0007] This objective is achieved by the device and the method according to the independent claims. Advantageous embodiments of the present invention are specified in the subclaims.

[0008] In particular, the objective is achieved by a device for correcting visual defects of an eye, including a coherent light source, a beam modification device for shaping and deflecting a beam of the coherent light source, provision being made for a wavefront analyzer device for analyzing a wavefront of the optical path in the eye. This device enables the data obtained from the analysis of the intraocular aberration to be taken into account in the correction of an existing optical system of an eye to be corrected. In this manner, the correction of the optical system of the eye is achievable with added precision.

[0009] The considered eye can be, in particular, a human eye but it is also conceivable to correct eyes of other living beings. Visual defects are, in particular, refractive visual defects such as myopia or hyperopia, irregularities of the cornea surface, or aberrations in the optical path.

[0010] Provided as coherent light source is preferably a laser, especially preferably a refractive laser, particularly preferably a spot scanning excimer laser. Conceivable is, moreover, a spot scanner using laser light in other ranges of the spectrum, such as a frequency-quintupled YAG laser, an IR laser of around 3 μm such as an Erbium:YAG laser emitting at 2.94 μm or a femtosecond laser (fs Laser).

[0011] The beam modification device is preferably composed of a device for shaping a beam and of a device for deflecting and aligning the beam. Preferably used as the device for shaping the beam are lens systems, diffractive structures, and refractive

elements. Preferably used as the device for deflecting and aligning the beam are scanner arrangements, prisms, and mirrors.

[0012] Preferably usable as wavefront analyzer device is a Shack-Hartmann sensor, which is a sensor that is based on a method for analyzing wavefronts and is used, in particular, in astronomy (see above). Using this wavefront analyzer device, it is possible to measure the whole wavefront emerging from the eye and, in this manner, to acquire data on the visual defects, including the intraocular aberration of the optical path also in the eye.

[0013] In a further exemplary embodiment of the present invention, provision is made for a device in which a topography analyzer unit for analyzing the surface of the eye is provided, as well. This analysis provides the data on the curvature and contour possessed by the eye surface, i.e., in particular by the cornea. In this manner, the complete data on the refractive visual defects of the eye is available to the system. Both the possibly not optimum surface contour of the eye, i.e., of the cornea, and the intraocular aberration can now be analyzed and are available to the system in the correction of the optical system of the eye. In this manner, it is possible to completely correct the visual defects of the eye and even to achieve a vision which exceeds that of the normal human eye.

[0014] In a further exemplary embodiment of the present invention, provision is made for a device in which, moreover, a control unit for processing signals of the wavefront analyzer unit and/or for processing signals of the topography analyzer unit and/or for controlling the coherent light source and/or for controlling the beam modification device is provided. These control units permit evaluation of the data ascertained by the analyzer units. It is possible for the signals of the wavefront analyzer unit and the signals of the topography analyzer unit to be separately processed and evaluated in the control unit, or to process both data sets in one step. The control unit is preferably composed of several individual control units.

[0015] This data is preferably used for providing an ideal optical system. The parameters required for beam modification is determined from this data. These parameters can preferably be used in a further step for controlling the coherent light source, for example, to predetermine amplitude, pulse duration, and energy of the beam. Moreover, these parameters are also preferably used for controlling the beam modification device; here, to predetermine the target spot and the geometry of the beam in the target via the deflection of the beam.

[0016] Because of this, it is possible in a preferred exemplary embodiment to calculate, in particular, the shot positions for manufacturing the individual elements.

[0017] In a further preferred exemplary embodiment of the present invention, provision is made for a device in which the beam modification device is designed in such a manner that an intraocular lens and/or an eye lens and/or the cornea of the eye and/or a contact lens and/or an implantable contact lens (ICL) and/or a spectacle lens are processable via the beam. The beam, which is preferably controlled by the control unit, now enables an element or workpiece of the lens system to be processed in such a manner that the visual defects or aberration are completely corrected. Such an element is preferably an intraocular lens (IOL) which is prefabricated prior to a corresponding operation. This is particularly preferably an ICL (implantable contact lens) which is placed onto the lens. Based on the entire available data on the visual defects, including the aberration of the eye, this IOL or ICL can be shaped in such a manner that it corrects all existing visual defects. It is also conceivable for the correction to be carried out on the eye lens itself with the assistance of the beam which is preferably controlled by the control unit.

[0018] Moreover, it is conceivable to carry out a correction by processing the cornea. It is also preferred to manufacture contact lenses which, in a patient-specific manner, correct all individual defects going beyond the refractive eye defect, such as aberrations, unsymmetrical cylinders, and irregularities of the cornea. Besides, it is also possible to manufacture individual spectacle lenses. Besides excimer spot processing, methods of the

optical industry, such as the single point diamond turning method, can also be used for this purpose. In this manner, all elements of the affected optical system can be used for correcting the eye defects.

[0019] It is also possible to use a combination of the individual (partly) corrected elements. This is an advantage, in particular if the theoretically possible correction via one element would result in excessive stressing of this element, and if such stressing appears not to be advisable, in particular from the medical point of view.

[0020] Moreover, the objective is achieved by a method according to the present invention for correcting visual defects of an eye, the optical path of the eye being determined via a wavefront analysis, and an ideal lens system being calculated which would result in a correction of the visual defects of the eye. This method is particularly preferably employed using a device according to the present invention. In this method, the intraocular aberration of the optical path is available for calculating the correction of the optical system for conversion into an ideal optical system.

[0021] In a further method according to the present invention, it is particularly preferred to analyze the topography of the eye as well. In this method, consequently, additional data on the defective vision of the eye is available, in particular on aberrations, unsymmetrical cylinders, and irregularities of the cornea.

[0022] In another preferred method, the ideal optical system is provided on the basis of the data obtained from the wavefront analysis and/or from the topography analysis. For this, it is particular preferred to provide only one element from this optical system. In this manner, the correcting element or the correcting elements is/are manufactured in a further step on the basis of the complete data of the defective vision. This procedure thus leads to the complete correction of the defective vision.

[0023] In a further preferred method, shot positions for manufacturing the ideal optical system are calculated using the data obtained from the wavefront analysis and/or

from the topography analysis. In this manner, it is advantageously possible to use the laser spot excimer method for manufacturing the individual elements of the optical systems. The shot positions are optimized depending on the materials to be used and considering the time needed for manufacture.

[0024] In another method of the present invention, the old optical system of the eye is reshaped into the calculated ideal optical system. To this end, either elements of the old optical system are processed directly or correspondingly corrected elements are manufactured and inserted or old elements are replaced with new elements. This method allows the old (defective) optical system of the eye to be converted into a (new) ideal optical system. It is especially preferred to manufacture a new lens or an ICL according to the spot scanning principle using an excimer laser.

[0025] The optical system preferably includes, as elements, the eye lens and/or an intraocular lens and/or the cornea of the eye and/or a contact lens and/or an ICL and/or at least one spectacle lens. Via refractive surgery, it is possible, for example, for the cornea of the eye to be reshaped so as to correct the existing defective vision (for example, the surface of the cornea via photorefractive keratectomy, PRK, or by ablation of inner tissue layers of the cornea using laser assisted in situ keratomileusis, LASIK). These elements not only feature rotationally geometric corrections but individual structures for correcting the defective vision of the patients. In this manner, it is possible to manufacture intraocular lenses or contact lenses, in particular ICLs which, once they are brought into the lens system, not only roughly correct the defective vision of the eye as in known methods heretofore but which additionally correct all irregularities, unsymmetries, and beam distortions, as well. In this manner, it is possible to attain a vision which exceeds that of the normal human eye. Besides, this method makes it possible to manufacture spectacle lenses which likewise correct all irregularities, unsymmetries, and beam distortions of the defective eye or of the old optical system, as well.

[0026] Moreover, the objective is achieved by an ideal optical system which is manufactured according to a method according to the present invention and/or using a

devices according to the present invention, the optical system including elements made of materials which are suitable for implantation and/or for adhesion and/or for ablation, in particular plastic or glass. By selecting these materials of the lens system according to the present invention, compatibility in using these elements is guaranteed. Such materials are, for example, PMMA, acrylic, silicone, or a combination of these materials.

[0027] In a further exemplary embodiment of the present invention, provision is made for an ideal optical system including elements which contain refractive and/or diffractive structures. In known methods heretofore, refractive and/or diffractive structures are only used in beam shaping. A minilens system guides and shapes the entering beam to attain a special beam distribution in the target plane. The use of such refractive and/or diffractive structures on individual elements of an optical system allows visual defects to be selectively corrected in an exceptionally ideal manner. Using these structures, it is thus possible to correct individual, non-steady aberrations but also to give the optical systems characteristics which a normal human eye does not possess.

[0028] The objective of the present invention is achieved, moreover, by an element of an (ideal) lens system having refractive and/diffractive structures. Such elements can include intraocular lenses, modified cornea, contact lenses, ICLs, or spectacle lenses.

[0029] In the following, exemplary embodiments of the present invention and advantageous refinements will be explained in greater detail on the basis of drawings. In this context,

[0030] Fig. 1 shows a block diagram for an exemplary embodiment of a device according to the present invention for correcting an aberration in the optical path of an eye.

[0031] Figure 1 depicts a block diagram for an exemplary embodiment of a device according to the present invention for correcting visual defects of an eye. A wavefront analyzer unit 2 and a topography analyzer unit 2' are connected to a control unit 3.

Control unit 3 is connected to a laser 4 and to a beam modification device 5 via a bus. A lens 6 is depicted downstream of beam modification device 5. An eye 1 is shown upstream of wavefront analyzer unit 2 and topography analyzer unit 2'.

[0032] In the operating state, the beams of wavefront analyzer unit 2 and topography analyzer unit 2' scan eye 1 and transmit the obtained signals to control unit 3. In control unit 3, the signals are processed and the ideal optical system for this eye 1 is calculated. In the depicted case, an ideal lens 6 is calculated here as element of the optical system. In control unit 3, in particular, all shot positions needed for laser 4 to manufacture ideal lens 6 are calculated on the basis of the data obtained from the signals, taking into account the laser-relevant data. Subsequently, control unit 3 triggers laser 4, determining energy and pulse rate of beam 7. Beam 7 is guided through beam modification device 5. In beam modification device 5, beam 7 is shaped and deflected via scanners and lens systems according to the calculated shot positions via the input of control unit 3, so that customer-specific lens 6 is manufactured by ablation of material on the raw lens via controlled laser beam 7. Preferably, control unit 3 can also be designed in several partial control units which can be connected to individual components of the device.

[0033] In this manner, a new and advantageous method and a device for completely correcting visual defects of the human eye have been specified. Combinations of measuring and processing methods have been specified which, when used according to the present invention, enable the human eye to be completely corrected. In doing so, measuring methods are used which can precisely measure the surface of the cornea and which also record the aberrations arising in the further optical path up to the retina. The computer-aided evaluation of these measuring results, in conjunction with the calculation of ideally corrected eye lenses (for example, after cataract operations) or of ideally correcting cornea surfaces, makes it possible to manufacture a patient-specific lens and/or to shape the cornea in an ideally correcting manner, preferably using a spot scanning excimer laser system in a topography-aided manner.

[0034] In particular, the correction can be effected via the modification of an element of the optical system. Thus, for improving the vision of a patient having a cataract and a defective vision, it is sufficient to completely correct the intraocular lens. In such a case, it is no longer necessary to carry out a refractive operation in addition to the cataract operation.

Claims

1. A method for correcting, in particular refractive visual defects of an eye (1), comprising
a coherent light source (4),
a beam modification device (5) for shaping and deflecting a beam of the coherent light source (4),
wherein provision is made for a wavefront analyzer device (2) for analyzing a wavefront of the optical path in the eye (1).

2. The device as recited in Claim 1,
wherein, in addition, provision is made for a topography analyzer unit (2') for analyzing the surface of the eye (1).

3. The device as recited in one of the preceding claims which are related to a device, wherein, moreover, provision is made for a control unit (3) for processing signals of the wavefront analyzer unit (2) and/or
for processing signals of the topography analyzer unit (2') and/or
for controlling the coherent light source (4) and/or
for controlling the beam modification device (5).

4. The device as recited in one of the preceding claims which are related to a device, wherein the beam modification device (5) is designed in such a manner that an intraocular lens and/or an eye lens and/or the cornea of the eye (1) and/or a contact lens and/or an implantable contact lens (ICL) and/or a spectacle lens are processable via the beam.

5. The device as recited in one of the preceding claims which are related to a device, wherein the coherent light source (4) is a laser, in particular a spot scanning excimer laser system.

6. A method for correcting, in particular refractive visual defects of an eye (1), in particular using a device as recited in the preceding claims,
wherein the optical path of the eye is determined via a wavefront analysis; and
an ideal optical system is calculated which would result in a correction of the visual defects of the eye (1).

7. The method as recited in Claim 6,
wherein the topography of the eye (1) is analyzed as well.

8. The method as recited in one of the preceding method claims,
wherein the ideal optical system is provided on the basis of the data obtained from the wavefront analysis and/or from the topography analysis.

9. The method as recited in one of the preceding method claims,
wherein, moreover, shot positions for manufacturing the ideal optical system are calculated with the assistance of the data obtained from the wavefront analysis and/or from the topography analysis.

10. The method as recited in one of the preceding method claims,
wherein the old optical system of the eye (1) is reshaped into the calculated ideal optical system.

11. The method as recited in one of the preceding method claims,
wherein the optical system includes the eye lens and/or an intraocular lens and/or the cornea of the eye and/or a contact lens and/or an ICL and/or at least one spectacle lens.

12. An ideal optical system manufactured according to one of the preceding method claims and/or using one of the devices as recited in the preceding claims which are related to devices,

wherein the optical system includes elements made of materials which are suitable for implantation and/or for adhesion and/or for ablation, in particular plastic or glass.

13. The ideal optical system as recited in one of the preceding claims which are related to an optical system,
wherein the optical system includes elements having refractive and/or diffractive structures.

14. An element for use in an optical system,
wherein the element has refractive and/or diffractive structures.

15. The use of a method as recited in one of the preceding method claims and/or of a device as recited in one of the preceding claims which are related to devices,
for completely correcting a visual defect of an eye.

CERTIFICATION OF TRANSLATION

I, Elise Duvekot, hereby certify that I am fully familiar with the German and English languages and that I am capable of translating from German into English. To the best of my knowledge and ability, the foregoing pages constitute an accurate and complete translation of the copy before me of PCT/EP00/07821 (DE 199 38 203.4) in the German language titled "Method and device for the complete correction of visual defects in the human eye". In witness whereof I sign,

Elise Duvekot Wassenaar, December 3, 2002.

Elise Duvekot, Translator

Öffentlich bestellte und beeidigte Urkundenübersetzerin und Dolmetscherin Elise Duvekot der englischen Sprache für Baden-Württemberg

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